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GRANT NsG 56-60

From

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

to

THE CALIFORNIA INSTITUTE OF TECHNOLOGY

by

Harrison Brown, Principal Investigator

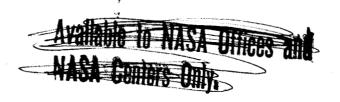Bruce C. Murray, Associate Principal Investigator

May 24, 1963

Pasadena, California

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CONTENTS

1. INTRODUCTION

This is a report of research activities carried out during the third year of grant NsG 56-60 from the National Aeronautics and Space Administration to the California Institute of Technology.

The Summary of Research, Section 2, is attached separately so that it may be circulated separately to a limited number of persons if such is desired. It is not as detailed as in the past, for reasons explained in section 2.1, and is not particularly intended for distribution outside official NASA personnel. We would welcome however, an opportunity to add to our regular mailing list additional names which might be suggested so as to broaden the distribution of our preprints.

The research staff supported by the grant leveled off during 1962. In fact, by the close of the year, the number of full-time personnel had been reduced somewhat. Dr. Murray (Research Fellow), Irene Goddard and Walter Nichiporuk (Chemists), Howard Pohn (Research Assistant), and Doreen Borrelli (Technical Aide) constitute the present full-time staff. Dr. Wildey, a full-time participant in our work is, nevertheless, supported in his Postdoctoral Fellowship mostly by Ford Foundation funds. Mr. Westphal, the third member of our "team" in many phases of the work, is a Senior Engineer in the Division of Geological Sciences and as such receives only part of his salary from the grant. Dr. Brown continues to be listed for salary purposes, as 1/4 time. Eleanor Helin (Research Assistant) has gone on to half-time status. Mrs. Evelyn Brown (unrelated to Dr. Brown) continues in her capacity as Administrative Aide and receives partial salary support. In addition, a clerk-typist was employed during most of the grant year. Graduate student participation in the grant activities is described separately in Section 3 of this report. Section 4 discusses briefly our liaison with the Space Program, while Section 5 presents a financial summary.

3. GRADUATE STUDENT PROGRAM

A major development in the establishment of an expanded, energetic program of graduate study in lunar and planetary science has taken place during the Winter and Spring of '62-'63. A new graduate program leading to a Ph.D. in Planetary Science within the Division of Geological Sciences has been approved and will become effective in the Fall of 1963. Four new graduate-level courses in lunar and planetary geology, geochemistry, and geophysics will be offered.* Significant new emphasis on planetary and interplanetary science is developing also in the Astronomy and Physics graduate programs. Accordingly, Caltech, which has been a leader in planetary and space research, now is taking steps to assume a role of corresponding importance in graduate student training in these fields.

During the grant year of 1962, one graduate student who has been supported by the grant, Hugh Millard, completed his Ph.D. work in meteorites (and chemistry). Another student under grant support, Alexander Goetz, Jr., initiated preliminary studies of the infrared properties of silicate minerals with possible applications to the Moon, and may do his Ph.D. thesis in this area. Kenneth Watson, also supported by the grant, is completing his vacuum thermal conductivity studies and related lunar analyses and is expected to have completed his Ph.D. work by about the middle of 1963. David Roddy is continuing his Ph.D. thesis investigation of the Flynn Creek, Tennessee, structure of possible impact origin. He has carried out an

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*Dr. Murray has accepted an appointment as Associate Professor of Planetary Science and will teach two of the new courses.

extensive investigation of shock-induced thermal luminescence in conjunction with his thesis investigation. His summer field work (under the supervision of Dr. Eugene Shoemaker) is supported by the United States Geological Survey while his laboratory and other investigations during the academic year are supported by the Grant.

Michael Duke, who has received minor support from the Grant, is completing his thesis on the petrography of basaltic achondrite meteorites under the supervision of Professor Leon Silver.

Two NASA traineeships have been made available to the Division of Geological Sciences and are being awarded at present. More will be requested in conjunction with a strong effort on our part to build up quickly the total graduate student enrollment in meteorites and lunar and planetary science to a goal of about 11 or 12, i.e., such that about 3 new Ph.D.'s a year would result from the Division of Geological Sciences alone. Inspite of the considerable publicity effort by NASA and others emphasizing the exciting new opportunities for research in the "space" age, it is no easy task to overcome the strong tendency of well-qualified prospective Ph.D. men in science to choose a traditional rather than a novel, relatively untried and cross-disciplinary field like planetary science.

One aspect of the NASA traineeship program that warrants mention here is that the immediate, short-term effect of making some 100 of these very well-supported 3 year stipends available throughout the country is to effectively <u>limit</u> our incoming graduate enrollment to about the number of new traineeships we will be able to offer each year; and this development is occurring at the very time we are initiating what we believe to be a genuinely new graduate program in this area. Any promising applicant

to graduate school who expresses even a passing interest in planetary
and space science is bound to be offered one of the 100 or so trainee-
ships throughout the country - perhaps even from a school which cannot
offer as good research and educational opportunities as Caltech. The
traineeship represents such a great amount of income compared to the usual
graduate research or teaching assistantship that it is expecting a lot
of a student to pass up a traineeship inorder to go "hungry" a bit at
what may be a better institution. Ironically, NASA has generated an
inflationary increase in planetary and space science graduate student
"labor" costs and we are caught with something of fixed wage scale and
hence have been put at a competitive disadvantage. A way around this
problem might be found if we were permitted to award a few one-year
(which we prefer to three-year awards anyway) fellowships in planetary
science out of Grant funds. These fellowships could be made to be
financially competitive with the traineeships and would provide us with
enough flexibility to compete effectively for the best-qualified prospec-
tive Ph.D. candidates in the country.

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4. RELATIONSHIP TO THE SPACE PROGRAM

Although our central interest is in the utilization of ground-based techniques for the investigation of the Moon, planets, and meteorites, direct participation in the space program seems desirable in certain areas. Dr. Brown has been carrying out a systematic investigation of meteorite and rock analyses as determined by an x-ray fluorescence technique comparable to that contemplated for use on the Surveyor vehicle. He is being assisted in this by Mr. Nichiporuk and Mrs. Helin (1/2 time). The Surveyor vehicle program itself has progressed at a slower rate than was anticipated at the time the supporting work under grant NsG 56-60 was initiated. Hence the lunar x-ray fluorescence experiment will be delayed substantially; the level of related work under 56-60 has also been reduced somewhat. The x-ray experiment is, however, a most important tool for the direct investigation of the lunar surface and the present "slowdown" should not change (and in our case has not changed) the ultimate objective of high quality x-ray fluorescence analyses of lunar surface materials for comparison with a vast background of similar analyses of meteorites and terrestrial rocks.

Dr. Murray continues to collaborate with Dr. Robert Leighton (and Dr. R. P. Sharp) on the design and development of a television experiment for the Mars Mariner mission in 1964. This mission has also experienced a major reduction in scope due to vehicle considerations. However, the TV experiment apparently will be flown, although with major reduction in total information to be recovered. Plans are presently being worked out with Dr. Leighton to begin studies of the effects on photogeological interpretation which may characterize TV pictures of low

geographic resolution compared with the usual aerial photographic material available in terrestrial applications.

Dr. Murray, in conjunction with Drs. Gerry Neugebauer and William M. Sinton, submitted a proposal in June, 1962 for a minimal infrared mapping experiment aboard the proposed surveyor-orbiter vehicle. To date we have not been informed of a decision by NASA in this regard.

Dr. Murray has, in addition, considered infrared experiments from probes in general as compared to what can be done from the ground and from balloons. Probe experiments in the infrared can be of considerable importance to the problem of remote determination of surface environments on the Moon and Mars but only by exploiting the potential of high geographic resolution. To do this appears to require at least moderate aperture instruments because of the high image motion characteristic of either fly-bys or orbital vehicles.

5. FINANCIAL SUMMARY

Summary and detailed information regarding expenditures during the grant year are presented in Tables I and II. In addition we wish to report the following equipment purchases in excess of $1000.00, in accordance with the stipulations of our grant.

1. Work Orders #90585 and #90544 to Central Engineering Services of Caltech for the design, fabrication, and servicing of a prototype 19 inch infrared telescope (but exclusive of the f/2 primary mirror which belongs to the Mount Wilson and Palomar Observatories). Total amount, $3500.00.

2. Purchase Order #66153X to the Ash Dome Company, Canton, Ohio for a 12'6" hand operated prefabricated dome. Total amount, $1408.25.

3. Purchase Order #68309X to Max Erb Company for the purchase of a petrographic microscope. Total amount, $2251.00.

TABLE I

Annual Expenditure Summary

Grant NsG-56-60

Year	Salaries and Benefits	Overhead	Materials* and Supplies	TOTAL
1 (1 Dec.'59 - 30 Nov.'60)	$31,301	$16,389	$14,878	$ 62,568
2 (1 Dec.'60 - 30 Nov.'61)	77,066	38,610	29,595	145,271
3 (1 Dec.'61 - 30 Nov.'62)	82,085	42,782	40,210	165,077

*Actual costs plus (or minus) difference in outstanding commitments at beginning and ending of Grant year.

TABLE II

YEAR 3

Expenditure Breakdown

Labor

1.	Salaries, professional personnel	$71,373.00
2.	Salaries, secretarial	6,500.00
3.	Labor charges, Institute (Engineering, transportation, etc.)	1,132.00
4.	Services, Division (Technicians and Analysis)	3,080.00
	TOTAL	$82,085.00

Overhead

1.	Applicable portion of items above	$42,782.00

Material

Laboratory equipment, misc., travel, etc.	$40,210.00

$165,077.00

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ATTACHMENT to Third Annual Report for Grant NsG 56-60, dated May 24, 1963

2. SUMMARY OF RESEARCH

2.1 INTRODUCTION

We are departing from the procedure used in the two previous

annual reports regarding description of research. Although the Summary

of Research section is still bound as a separate attachment to the

present report, as has been the case previously, we are not distributing

it widely nor is it as detailed as previously. The reasons for this

change back to a more conventional form of annual report are (1) We have

reached a stage where it is all we can do to get descriptions of our

work out in the form of preprints; and, (2) It appeared that relatively

few of the several hundred people to whom the Summary of Research section

was sent in the past read it carefully enough to warrant the considerably

increased preparation burden on our part.

In the present case, the relevant publications either by ourselves

or by others are referenced in the appropriate sections that follow.

Inasmuch as twenty-five copies of all preprints (if these are distributed

at all) and reprints are sent to NASA, additional copies are not included

here.

The topics in the following pages illustrate that our interests

are becoming increasingly observationally oriented, utilizing both teles-

copes and new laboratory tools as well as some of the more conventional

ones. The ultimate objective of the work remains unchanged, however.

This is the unraveling of the extraterrestrial physical, chemical and

geological records recorded in meteorites and on the surfaces of the

planets and the Moon.

Two relatively minor aspects of our work which are not included in the following are discussed by Roddy, et al in "Dynamic Penetration Studies in Crushed Rock Under Atmospheric and Vacuum Conditions", Technical Report No. 32-242, JPL, April 6, 1962; and Pohn in "New Measurements of Steep Lunar Slopes", Publications of the Astronomical Society of the Pacific, April 1963.

2.2 OBSERVATIONS OF 8-14 MICRON RADIATION FROM THE MOON, PLANETS, AND STARS

by

Bruce C. Murray, Robert L. Wildey, and James A. Westphal

In the last Annual Report brief reports were given on preliminary attempts to construct and operate an 8-14 micron photometer incorporating a mercury-doped germanium photoconductor cooled with liquid hydrogen. The photometer was successfully completed in the Spring of 1962 and then mounted on a specially-constructed, portable, 20 inch telescope located at 12,800' elevation on White Mountain, California (Westphal, Murray, and Martz 1963). During August and September of 1962 we were able to make measurements of emitted infrared radiation from the shaded (nighttime) lunar surface, obtaining both the lunation cooling curve observations into the first 160 hours of the lunar nighttime and observations of anomalously high temperatures from certain lunar areas (Murray and Wildey, 1963 a,b). We also obtained the first observations of 8-14 micron radiation emanating from outside the solar system, from the star α Ori (Murray and Wildey 1963a).

During October and December of 1962 we were permitted to place the photometer on the f/16 focus of the 200 inch telescope and observe both planetary and stellar objects during the morning and evening twilight periods. A total of 25 stars were observed (Wildey and Murray, 1963 a,b), as well as Jupiter and the Galilean satellites (Murray and Wildey, 1963 c) and Venus (Murray, Wildey, and Westphal, 1963). In addition, Westphal has been carrying out an extensive program of observation of atmospheric extinction and emission at White Mountain, Palomar, Mount Wilson, and elsewhere; preliminary results of this investigation will be presented in

June, 1963 (Westphal, 1963).

Because of the rapid expansion of this area of our work, and because
of its application to the general field of ground-based astronomy, supple-
mentary funds were requested from, and awarded by, the National Science
Foundation under Grant G-25210 from July 1, 1962 to June 30, 1963.

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    Astrophysical Symposium, University of Liege, Belgium, June, 1963,
    and published in the Proceedings.

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    Mapping of Venus Through the 8-14 Micron Atmospheric Window",
    Submitted to the Journal of Geophysical Research; A preliminary
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    Astronomical Photometer", Applied Optics, 2, 1963. (in press)

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    Symposium, University of Liege, Belgium, June, 1963, and published
    in the Proceedings.

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    Results and Future Prospects", to be presented at the 12th Annual
    Astrophysical Symposium, University of Liege, Belgium, June, 1963,
    and published in the Proceedings.

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2.3 PHOTOELECTRIC INVESTIGATION OF LUNAR BRIGHTNESS VERSUS PHASE

Robert L. Wildey
Howard A. Pohn

In the preceding annual report it was pointed out (Murray and Pohn, 1962) that implicit in the data of Fedoretz (1952) was a phase lag in the maximum brightness of lunar features; the greater the maximum brightness the greater the lag behind zero phase at which it is exhibited.

Feboretz' and most other brightness work has been based on pure photographic photometry which, in addition to possessing large random errors, frequently contains quite large scale and zero point errors.

We have made photoelectric observations during 8 lunations on a total of 16 nights, using the 60 inch telescope of the Mount Wilson Observatory, obtaining a total phase angle coverage of from 29° before minimum phase until 25° after minimum phase. The smallest minimum phase angle through which observations have been collected has been $1.^{\circ}9$. The data reduction is not yet complete and the need for collecting further observations remains a possibility. Only preliminary results can be mentioned here.

The data were collected using the 3-color direct photoelectric photometer of the Mount Wilson Observatory (Walker, 1957; Varsavsky, 1960; Wildey, 1962). Observations were made in the ultraviolet, blue, and yellow using 2-mm Corning 9863, 1.3-mm Schott GG13 plus 0.7-mm Schott BG12, and 2-mm Schott GG11 respectively. With the response function of the 1P21 photomultiplier, the three bands closely approximate those of the UBV magnitude-color index system of Johnson and Morgan (Johnson, 1955). On each night that the moon was observed, from 15 to 30

Johnson Standard stars were also observed (Johnson and Morgan, 1953).
Thus the photometric data for each night was corrected for atmospheric
extinction and transformed to the UBV system using a program developed
for the IBM 7090 by Abell (private communication). The data may thus
be compared in relative brightness and color with all the stars that
have been measured on this system or transformed to it. The major
part of the extinction error is also removed in this way. The real
significance, however, of using the UBV system is that it can now be
related to average watts/cm^2/steradian/angstrom and to an appropriate
effective-wavelength for each radiation band, through the absolute
calibration of a few bright stars by Willstrop (1962) and photoelectric
spectrum scans of stars of measured U, B, and V.

It now seems clear that the 25 features investigated, including
maria points, bright ray craters, and aged ray craters, all achieve
their maximum brightness at minimum phase; the data of Fedoretz are not
confirmed. A two-valuedness in the brightness versus phase relation,
where the choice of curves is fixed by whether the moon is waxing or waning,
appears to reflect that the light scattering law describing the lunar
surface is not degenerate in any of its three degrees of freedom. The
strong dependence on phase angle has been known for some time. In add-
ition a lesser dependence on elevation angles of the sun and of the observer,
respectively, removes the uniqueness of the observational brightness versus
phase. This is due to the fact that during a sequence of earthbound obs-
ervations the two elevation angles are functions of the phase angle in
a way which depends on the selenographic coordinates of a given lunar fea-
ture. The observations show that for features near zero longitude the
waxing and waning curves coincide, which is to be expected under the above

hypothesis, because in this case the two elevation angles are the same for waxing as for waning phase angles. For East selenographic longitude the waxing curve is steeper than the waning curve, the deviation between the two curves becoming greater the further east one goes.[*] One also sees a progressive deviation with West longitude, with, however, the waning curve being the steepest. This effect has been earlier reported by Van Diggelen (1959). These effects are implied by the non-degeneracy, in at least the elevation angle of the sun, of the aforementioned light scattering law. But, perhaps more important, this is true only under the assumption that the law is of the same general form over the whole lunar surface. This suggests that the form of the law is not strongly associated with the resolved geomorphology of the moon, except for the total diffuse plus specular reflectivity. The lack of universality over the lunar surface of the scattering law will not be known until the data have been subjected to further analysis.

These results are being prepared for publication, and attempts will be made later to fit models to the data that are based both on microtopographic shadowing and Mie scattering off of a plane-parallel atmosphere.

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[*](Astronomical East - not astronautical East)

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2.4 THERMAL CONDUCTIVITY OF POWDERS IN VACUUM

Kenneth Watson

The apparatus discussed in a previous annual report has been in use for the past academic year. The thermal conductivity of a variety of quartz, glass, and olivine powders are being measured and the results of this study and its application to the lunar $8 - 14\ \mu$ observations are being prepared for publication.

2.5 THE STABILITY OF VOLATILES IN THE SOLAR SYSTEM

Kenneth Watson, Bruce C. Murray, and Harrison Brown

We have extended our study of the stability of common volatiles (water, carbon dioxide, methane and ammonia) on the surface of the Moon (Watson, Murray and Brown 1961 a, 1961 b) to the surface of bodies in the solar system which do not have sufficient mass to retain a permanent atmosphere (Watson, Murray and Brown, 1963). The results of this study indicate that: (1) the lifetime of the most stable volatile ice, water, is determined by its evaporation rate at small heliocentric distances and by the Poynting-Robertson effect at large distances, (2) that the "dusty ice" model for comets provides insufficient shielding to retain volatiles for periods of time longer than a few million years in their present orbits, (3) that the Asteroid belt occurs at a heliocentric distance where the stability of water ice changes rather abruptly from stable to unstable in terms of a billion-year time scale.

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2.6 ON THE QUESTION OF LUMINESCENCE OF THE LUNAR SURFACE

David J. Roddy

An interesting consequence of the visible photometry of the moon has been the report of luminescence from certain areas of the lunar surface (Kozyrev, 1956; Dubois, 1957; Grainger and Ring, 1962). It has been suggested that this phenomena is consistent with the fact that certain minerals which are abundant terrestrially luminescence when irradiated with the appropriate electromagnetic or particle radiation. Furthermore, since no lunar atmosphere of consequence exists, solar ultraviolet, x-ray, and particle radiation are incident directly upon the surface of the Moon. Portions of this radiation are of course potential sources for excitation and emission in the visible spectrum.

Although only a limited amount of data have been published from actual lunar observations, the previous research in this phenomena has presented two interesting aspects, namely the large lunar areas reported to exhibit luminescence and their high emission intensities (in the order of 5-20% of the total reflected light). Both of these conditions, the size of the luminescent areas and the high luminescent intensities, however, have not been treated in any quantitative discussions. Using the published distribution and intensity data, the writer calculated the values for the relationships between the reported luminescence and certain fundamental parameters; the availability of sufficient excitation energy, the efficiency of emission, and the areal distribution.

Calculation of a simple energy balance equation utilizing the spectral distribution of solar energy and mean lunar albedos suggests that there

is sufficient energy in only broad band absorption (on the order of 1000 $\overset{\circ}{A}$ or more) to produce the observed visible emission. This is at variance with most terrestrial minerals which have relatively narrow short wavelength absorption bands on the order of only several hundred angstroms. Same data has been published attempting to relate solar flare activity to luminescence (Link, 1962) since variations in the short wavelength spectrum of the solar constant can change by several orders of magnitude. However, absence of appropriate observational data prevents proof of this relationship which potentially could provide sufficient narrow band absorption energy.

A second calculation was made relating the efficiency of emission and the areal distribution to the reported luminescence values. If a comparison is made of the efficiency - areal distribution combinations which are necessary to produce the reported luminescence it is clear that no normal terrestrial mineral assemblage or areal distribution could possibly fit the lunar observations. Efficiency values in excess of 10% coupled with areal distributions greater than 35% (percent of total area observed that is luminescent) would be necessary to produce the observational data. The efficiency limitation is particularly severe since _naturally_ occurring silicates (not commercial phosphorous) rarely have an emission efficiency as great as one percent.

If the observational data is indeed correct then clearly the luminescent material must have certain emission properties quite different from terrestrial materials. It is logical to expect severe radiation damage to have occurred and perhaps this could be the mechanism that has altered the solid state properties to allow an ease of excitation. This precise effect has not been experimentally investigated on the types of

minerals that one could expect on the lunar surface and sort can only
be suggested as a possible explanation.

Recourse to such an unusual (unusual terrestrially) geochemical or
a mineralogical distribution which could produce the observed data is
so removed from terrestrial experience that it cannot be argued at this
time.

During the lunar cycle when the sun's energy is not directed upon
the lunar surface there is a very small amount of energy received from
deep space. A simple calculation shows that even if all of this energy
could be stored in the surface minerals it could not account for the
reported level of luminescence. Needless to say the problem of radiation
damage complete with trace element activators and their relationship to
luminescence further compounds the difficulty of experimentally approaching
this problem.

The present state of the observational data suggests considerable
question may be applied to any luminescence interpretation for the surface
of the moon. This opinion is based predominately on terrestrial analogies
of efficiencies and areal distributions of _naturally_ occurring luminescent
minerals. If some special mechanism has been or is in operation, then
perhaps luminescence is possible. Hopefully, more precise laboratory and
telescope data which can be applied to this problem will be available
in the near future.

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2.7 METEORITE CHEMISTRY AND PETROGRAPHY

Walter Nichiporuk, Arthur Chodos, Eleanor Helin and Harrison Brown

During the past year, calcium, manganese, chromium, iron, nickel and cobalt have been determined by x-ray fluorescence on a number of important stony meteorites including representatives from chondrite and achondrite falls as well as finds.

Briefly, samples ranging in weight between 1 and 2 g (taken at random) are treated successively with 3.0N, 8.0N, and 15.0N nitric acid. After digestion solutions containing undisolved materials (silica, varying amounts of pyroxenes, chromite and the like) are evaporated to dryness and the solids are baked at 800°C. They are ground to pass 200 mesh. X-ray analyses are made in a Norelco Vacuum Spectrometer using 1 percent zinc - based on untreated air-dry samples - as an internal standard for iron, cobalt and nickel. The radiation is from a tungsten target and lithium fluoride and EDT analyzing crystals are suitably coupled with a Norelco flow proportional or a scintillation counter. The precise peak locations are determined by counting carefully over each peak. Counting statistics are sufficient to give relative standard error of 0.4 per cent and better.

The results have been promising. A series of synthetic standards and calibration curves have been prepared which are particularly appropriate for the measurement of the elements studied in silicate matrices of variable compositions.

A comparison of our preliminary results with the results obtained by other workers from wet chemical analyses is given in Table I. Additional comparison is given with determinations of chromium by neutron activation

(3) and of manganese by emission spectrography (11). The chondrite falls and finds are classified in the last column as being either the high (H) or the low (L) iron groups of Urey and Craig (1). With the exception of the Forest City chondrite fall, all classifications we list are new. A substantial fraction of these classifications, however, are not yet completely certain because our iron values for the chondrite finds in particular, appear to be consistently higher than the wet-chemical iron values and these dirrerences are sufficiently large to cause corresponding changes in the classification if the wet-chemical iron values are used instead of our present values. The cause of these differences is not entirely clear. It could result from the fact that at this stage of our analyses the statistics for most of the listed chondrite finds are poor and the single analyses we report for many of these finds have been made on powders that have been initially ground rather coarsely for the purpose of our exploratory determinations. This crude grinding could have given rise to large segregations in the composition, the structure and the relief of the powder surfaces which are actually the portions of the samples which are being analyzed in the x-ray fluorescence analysis. We have now carefully reground these powders to pass 200 mesh and will perform upon them new iron determinations exposing each time a new surface by vigorously shaking the powders in the holder prior to the analysis, which is really the procedure we have been following for all samples of falls.

There is no disagreement between x-ray fluorescence and wet-chemical iron values for Bruderheim, Mocs, and Kyushu chondrite falls, and also for the Mokoia carbonaceous chondrite fall. For the Abee enstatite-chondrite fall two wet-chemical iron values have been reported (4), the higher value for the groundmass and a lower value for a large fragment

which has been found as an inclusion in that groundmass. Our iron value is closer to that for the groundmass, although its precision is poor. A major source of error appears to be in micro-inhomogeneities in the powders which, as is obvious, are not completely eliminated even by grinding to a fine particle size.

The nickel results agree quite well with wet-chemical determinations of the element and no constant bias in any particular direction is evident. The calcium results are generally lower by about 10 percent than the wet-chemical calcium results and again, like in the case of iron, the differences seem to be greater for chondrite finds. By contrast, manganese is in a satisfactory agreement with both wet-chemical and spectrogrphic manganese. Our chromium results generally appear to be close to the average between the higher wet-chemical and the lower neutron-activation chromium values.

Some tentative observations can be made at this stage of our investigations. It is seen, for example, that the ratios of iron to nickel are generally much higher in achondrites than in chondrites. In Pasamont, which is a howardite, and in Shalka, which is a chladnite, these ratios seem to be a least as high as 1300.

Also, similar though smaller, variations exist in the ratios of chromium to manganese. The Mokoia carbonaceous chondrite has a ratio of 2.0, whereas ordinary chondrites have ratios of 1.0 or nearly 1.0, and the achondrites show a range of ratios from o.23 to 1.82. Except for the possible contributions from localized inclusions of chromite to the ratios which are greater than 1.0 in achondrites (Johnstown and Shalka), we have a sequence, carbonaceous chondrite-ordinary chondrites-achondrites, in which there is a progressive depletion of chromium relative to manganese. Whether or not this systematic sequence is correct and

whether or not it is also a genetically significant sequence, will perhaps become clearer when more carbonaceous chondrites and more members of the two broad subclasses of achondrites have been examined in our further studies.

Whereas it is clear that the individual chondrites which we have investigated in greater detail (e.g. Richardton) do not show any significant differences in the absolute concentrations of the elements studied, the Norton County achondrite does show significant differences in these concentrations from one sample to another, and the variations in iron and nickel appear to be in the same direction as the variations in calcium, manganese and chromium. This coherence between the two different groups of elements shows that the major proportion of iron and nickel in the stone is not in its sparse metal phase, but in the enstatite crystals where the ionic substitutions, rather than the element affinities determine the observed trends (e.g. Fe^{++} and Ni^{++} substituting for Mg^{++}, Mn^{++} for Fe^{++} and Mn^{++} for Ca^{++}).

During the last year a number of stony meteorites not listed in Table I have been obtained from Nininger Meteorite Collection, Arizona State University, and these are now being prepared for study. Thin sections of eighteen of these stones have been prepared. Samples have been also obtained from the American Museum of Natural History in New York and the Australian Museum in Sydney.

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TABLE I Values of Ca, Mn, Cr, Fe, Ni, and Co in Stony Meteorites*
by X-Ray Fluorescence*
(integral numbers denote ppm)

NAME	CLASS	Ca	Mn	Cr	Fe (total)	Ni	Co	IRON GROUPS
ABEE fell 1952	enstatite chondrite	0.91±0.04 0.74–0.60(4)0.20–0.55(4)	0.25±0.01	0.30±1.75 n.f.–tr.(4)	31.5±1.75 30.35–25.49 (4)	1.74±0.05 1.66–1.23(4)	905±35 700(4)	H
ACME found 1948	chondrite	1.24±0.04	0.22±0.01 0.20(11)	0.23±0.01	25.7±0.20	1.34±0.04	564	L
ALAMOGORDO found 1938	chondrite	0.91 1.06(10)	0.25 0.22(10) 0.24(11)	0.25 0.35(10)	30.40 28.40(10)	1.78 1.65(10)		H
ARRIBA found 1936	brecciated chondrite	1.00±0.01 1.21(10)	0.26±0.00 0.24(10) 0.24(11)	0.24±0.01 0.36(10)	22.68±0.10 20.90(10)	1.22±0.03 1.20(10)		L
BAXTER fell 1916	chondrite	1.22	0.25±0.01	0.25±0.02 0.23(3)	24.53±0.83	1.35±0.04	800	L
BEARDSLEY I fell 1929		1.17±0.03 1.14(12)	0.22±0.00 0.27(11) 0.22(12)	0.26±0.02 0.36(12)	29.10±0.10 26.76(12)	1.62±0.07 1.95(12)	805±5	
BEARDSLEY II	chondrite	1.15±0.04	0.24±0.01	0.27±0.02	27.40	1.66±0.06	770	H
BEARDSLEY III		1.19	0.24±0.01	0.27±0.01	27.65	1.57±0.04	680	
BRUDERHEIM fell 1960	hypersthene chondrite	1.24±0.04 1.27(8) 1.24(9)	0.26±0.01 0.25(8) 0.26(9)	0.26±0.01 0.36(8) 0.41(9)	23.0±0.6 22–29(8) 22.70(9)	1.25±0.03 1.22(8) 1.30(9)	460 500(9)	

NAME	CLASS	Ca	Mn	Cr	Fe (total)	Ni	Co	IRON GROUPS
CAVOUR found 1943	brecciated hypersthene chondrite	1.11 ± 0.03 1.15(10)	0.23 ± 0.00 0.22(10) 0.22(11)	0.25 ± 0.01 0.36(10)	$29.5_8\pm0.5_0$ 25.56(10)	1.65 ± 0.04 1.71(10)		H
COLBY fell 1917	hypersthene chondrite	0.92 ± 0.02	0.18 ± 0.02 0.20(11)	0.26 ± 0.00	$29.9_8\pm1.3_2$	1.61 ± 0.03	900	H
COVERT known bef. 1896	chondrite	0.81 1.02(10)	0.19 0.20(10) 0.21(11)	0.23 0.33(10)	29.0 23.7_9(10)	1.65 1.58(10)		H
FOREST CITY fell 1890	brecciated bronzite chondrite	1.04 ± 0.02 1.01(1) 1.04(10)	0.22 ± 0.01 trace(1) 0.23(10) 0.22(11)	0.29 ± 0.01 0.07(1) 0.20(3) 0.32(10)	$27.2_2\pm0.8_1$ 29.86(1) 23.09(10)	1.63 1.30(1) 1.62(10)	765 0.13(1)	H
FOREST VALE fell 1942	chondrite	1.14 ± 0.01	1.21 ± 0.01	0.27 ± 0.02	$29.5_7\pm0.3_1$	1.80 ± 0.06	815	H
GLADSTONE found 1936	chondrite	1.07 0.96(12)	0.22 0.26(11) 0.20(12)	0.25 0.041(12)	29.0_0 25.83(12)	1.65 1.46(12)		H
HOLBROOK I fell 1912		1.13 ± 0.07 1.24(5)	0.24 ± 0.02 0.29(5) 0.24(11)	0.27 ± 0.01 0.22(3) 0.31(5)	$23.1_5\pm0.6_5$ 21.56(5)	1.38 ± 0.03 1.09(5)	620 520(5)	
HOLBROOK II	hypersthene chondrite	1.19 ± 0.03	0.25 ± 0.01	0.25 ± 0.01	$21.5_1\pm0.6_1$	1.27 ± 0.03	460	L
HOLBROOK III		1.17 ± 0.01	0.25 ± 0.01	0.27 ± 0.01	$21.7_0\pm0.6_5$	1.13 ± 0.03	400	
HOLBROOK IV		1.22	0.25	0.31	$22.0_0\pm1.2_0$	1.17	425	

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NAME	CLASS	Ca	Mn	Cr	Fe (total)	Ni	Co	IRON GROUPS
HUGOTON found 1927	brecciated chondrite	0.82 1.07(10)	0.22 0.20(10) 0.20(11)	0.23 0.34(10)	28.8_0 $25.1_3(10)$	1.43 1.36(10)		H
JOHNSTOWN fell 1924	chladnite (diogenite)	1.02±0.01 1.87(1) 1.16(12)	0.37±0.03 0.31(1) 0.35(11) 0.36(12)	0.46±0.01 0.68(1) 0.32(3) 0.48(12)	$12.4_2±0.4_6$ 12.42(1) 12.56(12)	143±5 300(1) 200(12)	64±1	
KYUSHU fell 1886	chondrite	1.21±0.01 1.21(6)	0.26±0.02 0.26(6)	0.26±0.02 0.37(6)	$21.8_9±0.4_4$ 22.02(6)	1.15±0.03 1.34(6)	775 460(6)	L
LA LANDE found 1933	hypersthene chondrite	0.99 1.13(10)	0.23 0.25(10) 0.22(11)	0.22 0.34(10)	24.5 $20.5_9(10)$	1.29 1.01(10)		L
LADDER CREEK found 1937	chondrite	1.08 1.28(10)	0.25 0.24(10) 0.24(11)	0.21 0.37(10)	22.3_0 20.44(10)	1.12 1.06(10)		L
MOCS fell 1882	hypersthene chondrite	1.21 1.29(7)	0.26±0.01 0.28(7) 0.27(11)	0.26±0.02 0.41(7)	$21.4_7±0.4_6$ 21.81(7)	1.25±0.04 1.25(7)	505 570(7)	L
MOKOIA I fell 1918	carbonaceous chondrite	1.70±0.01 1.83(2)	0.15±0.00 0.12(2)	0.31±0.01 0.36(2)	$24.9_4±0.3_1$ 24.05(2)	1.34±0.02 1.29(2)	600±10 630(2)	L
MOKOIA II	carbonaceous chondrite	1.65±0.02	0.15±0.00	0.32±0.01	$24.2_7±0.0_4$	1.34±0.03	593±2	L
MOKOIA III		1.64	0.15	0.30	25.0_0	1.38±0.01	595	
MORLAND found about 1890	chondrite	1.02 1.09(12)	0.22 0.25(11) 0.22(12)	0.21 0.26(12)	26.8_0 24.7_2	1.57 1.52(12)		H

NAME	CLASS	Ca	Mn	Cr	Fe (total)	Ni	Co	IRON GROUPS
NORTON COUNTY I fell 1948		1.12+0.01 0.47(2) 1.16(12)	0.25+0.01 0.12(2) 0.11(11) 0.18(12)	586+5 480(2) 680(12)	1.52+0.1 1.60(2) 1.07(12)	452+35 400(2) 680(12)	9 (extrap.) (2)	
NORTON COUNTY II	bustite (aubrite)	0.94+0.01	640+10	153+9	<<1.0	102+2	<10	
NORTON COUNTY III	bustite (aubrite)	1.50+0.01	0.15+0.00	391+13	<1.2	247+2	<10	
NORTON COUNTY IV		1.16+0.01	0.14+0.01	412+3	~1.2	250+6	9	
OCHANSK fell 1887	brecciated bronzite chondrite	1.10+0.01 1.14(2)	0.22+0.00 0.20(2) 0.24-0.27(11)	0.28+0.02	27.7+2.1 27.9(2)	1.71+0.03 1.58(2)	855+10 0.10(2)	H
PANTAR fell 1938	chondrite	1.19+0.05 1.29(10)	0.23+0.01 0.24(10) 0.23(11)	0.27+0.01 0.36(10)	25.6+0.7 25.68(10)	1.52+0.04 1.76(10)	655	L
PASAMONTE fell 1933	howardite	>>1.65 7.33(12) 7.31(1)	0.35+0.01 0.43(12) 0.33(1)	983460 0.23(12) 0.21(1)	13.3+0.2 15.26(12) 16.00(1)	<100 0.00(12)	55+3	
RANSOM recognized 1938	chondrite	0.96+0.02 1.06(10)	0.22+0.01 0.22(10) 0.23(11)	0.23+0.01 0.36(10)	26.1+1.8 25.27(10)	1.54+0.08 1.62(10)		L
RICHARDTON I fell 1918	bronzite chondrite	1.11+0.01	0.23+0.00 0.26(11)	0.26+0.01 0.24(3)	27.4+0.2	1.57+0.06	718+3	H
RICHARDTON II	bronzite chondrite	1.10+0.01	0.23+0.00	0.25+0.01	27.6	1.63+0.04	800	
RICHARDTON III		1.14+0.02	0.24+0.00	0.27+0.02	26.7	1.71+0.04	695	

NAME	CLASS	Ca	Mn	Cr	Fe (total)	Ni	Co	IRON GROUPS
SHALKA I fell 1850	Chladnite	<0.60 0.06-0.64(1)	0.44+0.02 0.45(11)	0.80+0.26 0.86-1.12(1)	13.5 $\pm0.9_1$ 13.31-14.73 (1)	<100	59+4	
SHALKA II	(drogenite)	<0.60	0.49+0.02	0.72+0.03	12.9 $\pm0.1_9$	<100	69+1	
SHAW found 1937	Amphoterite	0.86+0.04 1.28(12)	0.27+0.02 0.24(11) 0.26(12)	0.23+0.01 0.19(12)	17.1 $\pm0.6_4$ 16.93(2)	0.66+0.03 0.80(12)	24+8	

2.23

*The X-ray fluorescence values, which in most cases are averages of 2-12 determinations, are listed first for each meteorite. Values by other methods are given directly under the X-ray fluorescence values. The Roman minerals denote different samples of the same meteorite. For these meteorites, the values by other methods are always given with samples denoted by I. The minerals in parentheses denote literature references listed below.

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2.8 METEORITE AND ASTEROID SYSTEMATICS

Irene Goddard, Hugh Millard and Harrison Brown

A statistical study has been made of some of the non-random aspects of the frequency of meteorite fall as function of time. In the interval of 1 - 1000 days, non-random assemblages have been found at periods other than one day and one year, together with integer multiples thereof. Although it is possible that some of the assumed periods are "real" in the sense that they have physical significance, the statistics make this appear unlikely.

The least random assemblage in the neighborhood of one-year does not occur at exactly one year (365.24 days). Instead there appear to be two particularly non-random assemblages, the first at about 364.46 days and the second at 366.1 days. The latter appears to be linked with the high-iron chondrites. The reasons for this curious behavior are unknown.

Histograms showing the number of falls which have been observed during specific times of the year, dividing the year into 20 equal parts, indicate a maximum in late January due to low-iron chondrites, one in mid-May due to high iron chondrites and one in late August and early September resulting from low-iron chondrites. The relative frequencies of the groups appear to change with time.

Indications of "clustering" of meteorites in orbit have been obtained by plotting the time of fall during a year against the time of fall in a period consisting of an integer number of years. Marked clustering is noticeable in the high-iron chondrites as well as in the veined-hypersthene chondrites on a five-year period.

As an example of a cultural effect upon the observed rate of meteorite fall, it has been found that in Western Europe and in North America, which are predominatly Christian regions, observed daytime falls on Sundays are about 30% lower than average and nearly 40% lower than the average excluding Sundays. Although this difference is appreciable, it is surprisingly small.

The accumulated evidence strongly suggests that the non-randomness of the observed rate of fall of meteorites as a function of time of year is due primarily to astronomical factors rather than to cultural ones.

The histogram of falls per decade contains at least three peaks and a sharp decrease after 1940 which is believed to reflect a decrease in the rate of influx of meteorites. The yearly fall pattern of the calcium rich achondrites parallels the peaks in the falls per decade histogram very closely.

The meteorite statistics are being processed further. In addition, the orbital characteristics of 1653 asteroids have been placed upon punch cards. This marks the beginning of an effort aimed at determining further relationships between meteorites and asteroids.

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